Percutaneous Chest Tube for Pleural Effusion and Pneumothorax

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Abstract

Chest tubes are placed in the pleural space to evacuate abnormal fluid or air accumulations. Various types and sizes of chest tubes are available. Imaging including ultrasound, computed tomography, and fluoroscopy should be used to guide chest tube placement. Understanding the anatomy of the pleural space, along with the etiology and classification of pleural space disease, can help optimize chest tube management. This article will review the indications, contraindications, techniques, and postprocedure follow-up of chest tube placement as well as discuss the management and prevention of complications.

Keywords

- percutaneous chest tube
- thoracostomy tube
- pleural effusion
- pneumothorax
- pleural drain
- interventional radiology

Chest tube placement is the most common procedure for the treatment of a variety of pleural space diseases including pneumothoraces and pleural effusions. Chest tubes can be used for draining fluid or air in the pleural cavity as well as serve as a route for installation of antibiotics, sclerosants, fibrinolytics, or saline. Small ($\leq$14 Fr) or large bore ($>$14 Fr) chest tubes can be placed for adequate drainage depending on the etiology and classification of pleural disease. This article will focus on the anatomy and pathology of the pleural space, indications, contraindications, techniques, and postprocedure follow-up of percutaneous chest tubes with a primary focus on the treatment of pleural effusion and pneumothorax. In addition, the challenges and complications of chest tube management will also be discussed.

Pleural Space Anatomy

The pleura is a two-layered serous membrane composed of simple squamous epithelium. The outer layer is the parietal pleura which lines the chest wall, diaphragm, and mediastinum. The inner layer is the visceral pleura which lines the lung. These two layers are continuous with each other at the root of the lung forming the pleural cavity, a closed potential space. The visceral pleura receives its blood supply from the bronchial circulation, while the parietal pleura receives its blood supply from the intercostal arteries. The parietal pleura contains pain receptors and is highly sensitive to pain, while the visceral pleura lacks sensory innervation.

The distance between the parietal and visceral pleural space normally measures 15 to 20 microns wide and contains approximately 5 to 10 mL of sterile serous fluid, which continuously lubricates the pleural surface to allow easy movement during lung inflation and deflation.[1] The surface tension of the fluid in the pleural cavity also secures the pleura together and allows the thoracic cavity to expand during inspiration. When air enters the pleural space, the surface tension dissipates, resulting in a pneumothorax. Similarly, abnormal fluid accumulation in the pleural space causes a pleural effusion.

►**Fig. 1** demonstrates typical anatomy of the pleural space.

Collections in the Pleural Space

Pleural Effusion

Approximately 1.5 million pleural effusions are diagnosed annually in the United States and are one of the major causes

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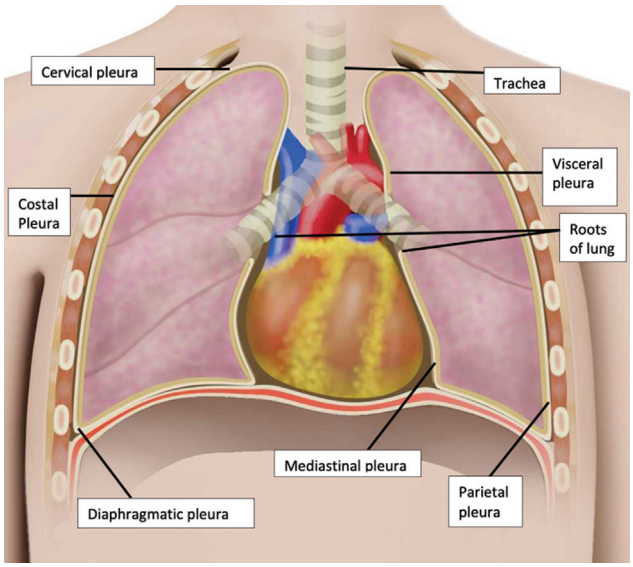

Fig. 1 Anatomy of the pleural space. Pleura consists of a layer of simple squamous cells supported by connective tissue. The visceral pleura lines the lungs and the parietal pleura lines the thoracic cavity. These two parts are continuous and the transition from visceral pleura to parietal pleura occurs at the root of each lung. The parietal pleura can be subdivided into mediastinal, cervical, costal, and diaphragmatic pleura.

of pulmonary morbidity and mortality.[2] An imbalance of fluid secretion and fluid absorption within the pleural space leads to a pleural effusion. Two common classification systems are used to describe pleural fluid by the appearance/composition of the pleural fluid or etiology (►**Table 1**).

Classifying the etiology of the pleural fluid as transudative or exudative assists in identifying the underlying disease process and guides management. Transudative effusions are caused by an imbalance of pulmonary capillary hydrostatic pressure and plasma oncotic pressure, which influences the reabsorption and formation of pleural fluid. The most common cause of transudative effusion is heart failure.[3] In contrast, exudative effusions are triggered by damage to the pleural membrane causing increased capillary permeability or decreased lymphatic resorption. The most common causes of exudative effusion are pneumonia and malignancy.[3] It is important to distinguish this difference because transudative effusions improve with the treatment of the underlying systemic condition (i.e., diuretics for heart failure).

Light's criteria is a widely accepted analysis that allows the differentiation between transudative and exudative effusions. Pleural fluid is sampled via thoracentesis and compared against serum fluid. The effusion is considered exudative if one of the following are present: (1) the pleural fluid:serum protein ratio is greater than 0.5, (2) the pleural fluid:serum lactate dehydrogenase (LDH) ratio is greater than 0.6, or (3) the pleural fluid LDH concentration is greater than two-thirds the upper limit of normal for serum LDH. Any one of these criteria being present predicts an exudative effusion with a 94.7% accuracy.[4] If the pleural effusion is exudative by Light's criteria, but there is clinical suspicion that the fluid may be transudative, a serum-to-pleural fluid albumin level should be calculated. If the serum albumin level is 1.2 g/dL higher than the pleural fluid albumin level, then the fluid is transudative.

Further analysis of the pleural fluid is needed to narrow down the differential diagnosis in the case of exudative effusions. Fluid is routinely sent for total and differential cell counts, cytology, pH, glucose, and adenosine deaminase. ►**Table 2** identifies the routine and optional diagnostic laboratory tests that aid in the differential diagnosis.

The clinical presentation can vary depending on the underlying cause, type, and severity of pleural effusion. Patients may be asymptomatic or experience pleuritic chest

Table 1 Classification systems of pleural effusions

Appearance/Composition	Etiology of pleural fluid	
	Transudate	Exudate
Hydrothorax Hemothorax Empyema/pyothorax Chylothorax Bilious	Congestive heart failure Nephrotic syndrome Liver cirrhosis Hypoalbuminemia Atelectasis Peritoneal dialysis Pericarditis Urinothorax Myxedema CSF fluid leak	Pneumonia (parapneumonic) Empyema Tuberculosis Malignancy Pulmonary embolism Pancreatitis Autoimmune disease (lupus, rheumatoid arthritis, connective tissue disease) Post–cardiac injury syndrome Asbestos Lymphatic disruption Esophageal perforation Medication-induced (methotrexate, amiodarone, phenytoin, dasatinib) Ovarian hyperstimulation syndrome Meigs syndrome Dressler syndrome

Abbreviation: CSF, cerebrospinal fluid.

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Table 2 Pleural fluid tests and related differential diagnosis

Routine tests	Result	Differential diagnosis
Adenosine deaminase	>40 U/L	Tuberculosis (90%) Empyema (60%) Complicated parapneumonic (30%) Malignancy (5%) Rheumatoid arthritis
Cytology	Present	Malignancy
Gram stain and culture	Positive	Infection
Glucose	<60 mg/dL	Infection (20%) Malignancy (<10%) Rheumatoid arthritis
RBC count	>100,000 per mm^3	Malignancy Trauma Parapneumonic Pulmonary embolism
WBC count	>10,000 per mm^3	Empyema
Lymphocytes	>50%	Malignancy Tuberculosis Pulmonary embolism Coronary artery bypass surgery
Neutrophils	>50%	Parapneumonic Pulmonary embolism Pancreatitis
Eosinophils	>10%	Medication reaction Idiopathic Asbestos Infectious Inflammatory Malignancy (Kager)
Additional pleural fluid tests		
Amylase	>Upper limit of normal	Malignancy (20%) Pancreatic disease Esophageal rupture
Cholesterol	>45 to 60 mg/dL	Nonspecific exudate
Hematocrit pleural fluid to blood ratio	>0.5	Hemothorax
Interferon	Various cutoff points	Tuberculosis
pH	<7.2	Complicated parapneumonic Empyema Malignancy (<10%) Tuberculosis (<10%) Esophageal rupture
Polymerase chain reaction for *Streptococcus pneumoniae* and *Mycobacterium tuberculosis*	Positive	Infection
Triglycerides	>110 mg/dL	Chylothorax
Tumor markers	Various cutoff points	Malignancy
NT-proBNP	>1,500 pg per mL	Heart failure

Abbreviations: NT-proBNP, N-terminal pro-brain natriuretic peptide; RBC, red blood cell; WBC, white blood cell.

pain, shortness of breath, or nonproductive cough. A large amount of fluid in the pleural space can affect cardiac activity due to decreased ability for cardiac distention and filling.

Diagnostic signs on chest radiograph include blunting of the costophrenic angle, fluid within the fissures, or a meniscus. In the upright position, a lateral view radiograph allows detection of as little as 50 mL of fluid, whereas a posteroanterior view requires 200 to 500 mL of pleural fluid for visibility.[5] A lateral decubitus radiograph can also help evaluate free flowing or loculated effusions. Ultrasound is useful for the diagnosis of very small pleural effusions (3–5 mL) and differentiating transudative and exudative effusions. Computed tomography (CT) helps characterize specific pleural–parenchymal processes.

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Pneumothorax

Pneumothorax is diagnosed in approximately 20,000 cases annually in the United States and occurs when there is an abnormal accumulation of air between the parietal and visceral pleura.[6] Air can accumulate in the pleural space due to a communication with the atmosphere, airway, or due to the presence of gas-forming organisms within the pleural cavity. The excess air disrupts the negative pressure gradient of the pleural cavity, which is responsible for the surface tension between the parietal and visceral pleura and interferes with dynamic movement between the chest wall and lung. Loss of the intrapleural negative pressure results in lung collapse which ultimately decreases lung vital capacity and ventilation.

A pneumothorax is classically categorized as spontaneous or acquired (►**Fig. 2**). Spontaneous pneumothorax can be differentiated into primary spontaneous pneumothorax (PSP), due to no elicit cause, or secondary spontaneous pneumothorax (SSP), occurring due to an underlying pulmonary disease. Acquired pneumothorax can be iatrogenic or due to blunt or penetrating trauma. Pneumothoraces can also be further categorized into simple or tension. Tension physiology is the result of a one-way valve created in the pleural cavity that allows progressive air accumulation in the pleural space with each respiratory cycle that cannot fully exit. This exerts mass effect on the mediastinum, impeding venous return, leading to cardiorespiratory compromise and cardiac arrest.

Patients may range from asymptomatic in the case of a small PSP to hemodynamically unstable in the case of a tension pneumothorax. Typical symptoms include chest pain and dyspnea. In general, the clinical symptoms associated with PSP are less severe than those associated with SSP, and most patients with SSP experience breathlessness that is out of proportion to the size of the pneumothorax. These clinical manifestations are therefore unreliable indicators of the size of the pneumothorax.

Diagnostic signs on chest X-ray include displacement of the pleural line, collapsed lung, or mediastinal shift in the case of a tension pneumothorax. An upright posteroanterior chest radiograph detects pneumothorax with sensitivity as high as 92%. Trauma and critically ill patients are frequently limited to supine or lateral decubitus imaging. In the supine projection, chest radiography is less sensitive and reported at 50%.[7] If there is any uncertainty, a CT scan should be obtained, which is regarded as the best method for size estimation and detection of small pneumothoraces. Ultrasound has also been shown to be useful for rapid diagnosis of pneumothorax at the bedside.[8]

Percutaneous Chest Tube Placement

Indications and Contraindications

The most common indications for chest tube placement are exudative effusions, empyema, hemothoraces, pneumothoraces, and post–thoracic surgery (►**Table 3**). Small uncomplicated effusions can be observed unless respiratory function is impaired. Transudative effusions may resolve or decrease in size when the underlying cause is treated. For example, pleural effusions due to congestive heart failure resolve using diuretics alone in 75% of cases.[9] However, pleural effusions that do not improve with medical management, effusions causing respiratory insufficiency, malignant effusions, complicated parapneumonic effusions, and empyemas should be sampled and will likely require drainage.[3]

Chest tubes are indicated for pneumothoraces with a known underlying cause that has a high suspicion for a continued air leak or recurrence without intervention. Spontaneous pneumothoraces and iatrogenic pneumothoraces are unlikely to have a continued air leak and can be managed

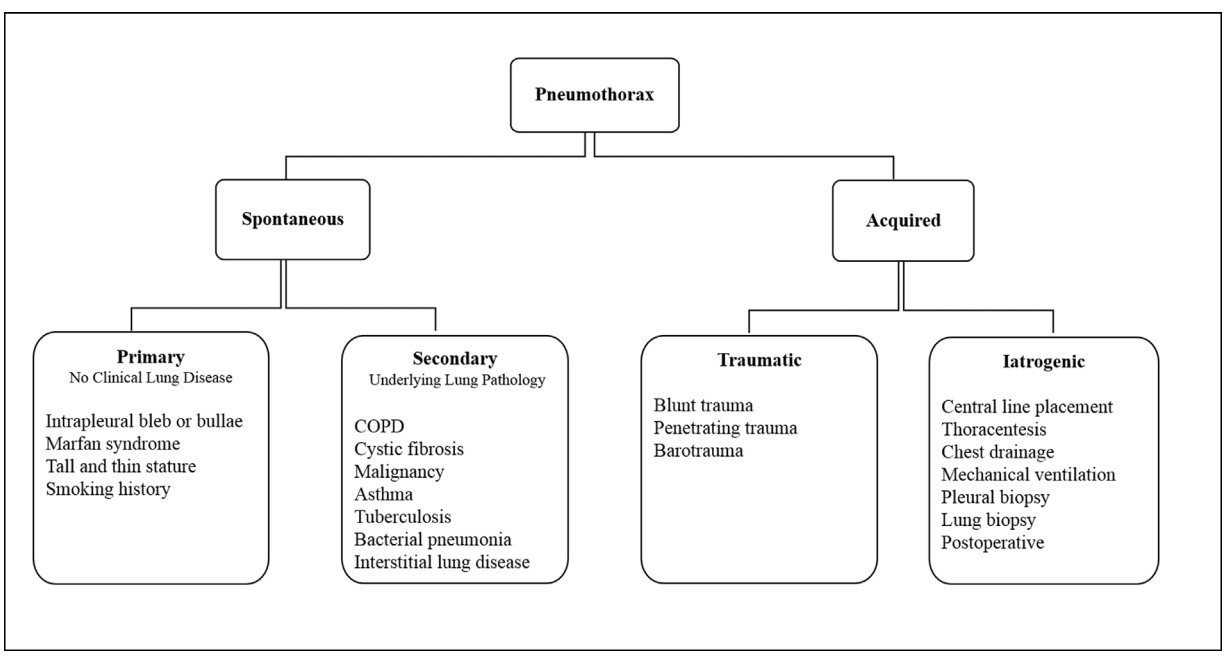

Fig. 2 A flowchart for the classification of pneumothorax. COPD, chronic obstructive pulmonary disease.

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Table 3 Indications for chest tube placement

Pneumothorax	Any size pneumothorax with cardiorespiratory compromise
	Large or symptomatic primary spontaneous pneumothorax[a]
	Large or symptomatic secondary spontaneous pneumothorax[a]
	Large or symptomatic iatrogenic pneumothorax
	Traumatic pneumothorax
	Tension pneumothorax[b]
	Pneumothorax on positive pressure ventilation
Pleural effusion	Infected effusion
	Hemothorax
	Chylothorax
	Malignant effusions
	Benign effusions requiring pleurodesis
	Effusion on positive pressure ventilation that is symptomatic/difficult to wean
Postoperative	Thoracic, cardiac, esophageal surgery
	Thoracoscopy

[a]As alternative to needle aspiration or after its failure.
[b]Needle aspiration used initially in life-threatening situations.

conservatively with observation and supplemental oxygen. High-flow oxygen is shown to improve the resorption of pneumothoraces quicker than observation alone.[10] In general, chest tube placement will be needed for any size pneumothorax associated with impaired cardiorespiratory status; large spontaneous and iatrogenic pneumothoraces after needle aspiration failure; and traumatic, tension, bilateral, or positive-pressure pneumothoraces. These pneumothoraces are at high risk for continued air leak. Occult traumatic and small pneumothoraces on positive pressure ventilation can be managed conservatively, but there is a high risk for decompensation, and a lower threshold for chest tube placement should be considered.[11]

The only absolute contraindication to chest tube placement is lung completely adherent to the chest wall.[12] Few relative contraindications include overlying chest wall infection at the insertion site, increased risk of bleeding, and coagulopathy. However, chest tube placement can be performed relatively safely in patients with elevated international normalized ratio.[13]

Type and Size of Chest Tubes

Commercially available chest tubes vary significantly in their types, shapes, and sizes. Chest tubes can be made of soft silicone, polyethylene, or polyvinyl chloride. Heparin-coated chest tubes are also available but have demonstrated limited effectiveness at preventing clot formation.[14] Chest tubes can have a straight, angled, or pigtail shape. Conventional chest tubes have an end-hole and multiple side-holes at the proximal end with a radiopaque maker to denote the first drainage hole.

Chest tubes are measured by their internal diameter ranging in sizes from 6 to 40 Fr. Although not standardized, small bore chest tubes are defined as $\leq$14 Fr and large bore chest tubes are defined as >14 Fr. Typical chest tube lengths range from 30 to 40 cm. The decision to use a large bore versus small bore catheter remains controversial and there is a lack of randomized data. Traditionally, large bore chest tubes were used because of the potential for greater flow rates, faster evacuation, and concern that smaller chest tubes were more likely to occlude or kink.[14] However, there is a shift toward using smaller chest tubes, as they have been shown to be effective in the evacuation of pleural collections with fewer associated complications and less pain.[15] The lower risk of complications with small bore chest tubes is generally accepted; however, their effectiveness compared with large bore chest tubes is still debated.

A meta-analysis by Chang et al found that drainage duration and hospital stay were shorter with pigtail catheters (8–14 Fr) and complication rates were significantly lower compared with large bore catheters in the treatment for pneumothorax.[16] Similarly, a comparative study found smaller chest tubes were as effective as larger chest tubes in terms of initial pneumothorax resolution and hospital length of stay.[17] The rate of flow is more likely to be a concern for pneumothoraces with a persistent air leak (PAL) and thick exudative fluid collections where large bore chest tubes can be of value.[18,19] An observational study including 1,092 patients found that patients with empyema were 10.7 times more at risk of drainage failure and had increased drainage days compared with malignant effusions, nonmalignant effusions, and pneumothoraces.[20] Conversely, a prospective trial found similar outcomes in failure rate and initial drainage rate for small bore (14 Fr) catheters compared with large bore catheters (32–40 Fr) for traumatic hemothorax/hemopneumothorax.[21] Large bore chest tubes may be advantageous for hemothorax, empyema, PAL, pneumothorax on mechanical ventilation, and postoperative collections.

Image-Guided Techniques for Chest Tube Placement

The first step involves choosing the optimal placement for chest tube insertion based on the location and characterization of the air/fluid collection (i.e., free flowing or loculated) as well as the patient's positioning. Chest tubes placed for pleural fluid are commonly directed inferiorly and posteriorly, while chest tubes placed for pneumothorax are directed toward the lung apex (►**Fig. 3**). Multiloculated collections require preprocedural planning with imaging. Placement superior to the rib margin is ideal to avoid injury to the intercostal neurovascular bundle.

Image Guidance

Ultrasound, fluoroscopy, CT, or a combination of these techniques can be used to guide access into the pleural space and perform interventions. Choice of imaging modality

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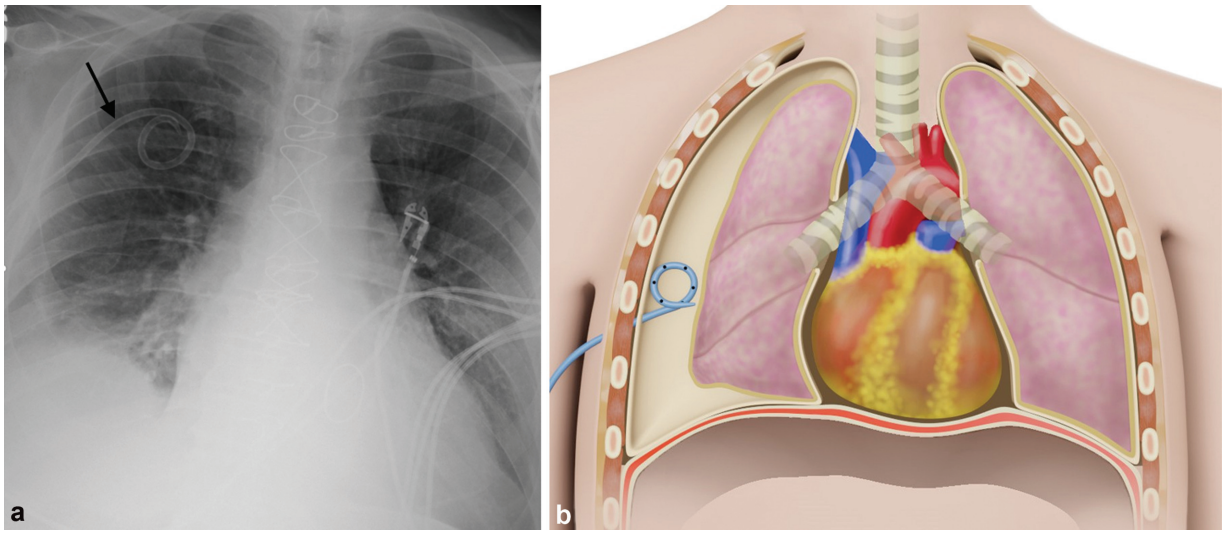

Fig. 3 A 76-year-old man with a history of atrial fibrillation and severe mitral regurgitation status post cardiac surgery complicated by pneumothorax. (**a**) Frontal chest radiograph demonstrates an apically directed 12-Fr chest tube (arrow) placed under fluoroscopic guidance. (**b**) Illustration of chest tube placement directed apically for pneumothorax.

depends on multiple factors including size of the collection, the availability of the modality, the presence of air or fluid within the collection, the patient's clinical condition, and radiologist's preference.

Ultrasound is the standard of care for drainage of pleural collections. Real-time procedural guidance helps increase success rate and reduce extrathoracic placement, lung injury, or malpositioning (►**Fig. 4**).[22] Benefits also include lack of ionizing radiation, low cost, easy accessibility, and portability which is ideal for bedside chest tube placement and allows placement in nearly any patient position. However, ultrasound is limited in visualizing air-filled collections, fluid collections deep to bony structures, or fluid collections near the scapula, paramediastinum, or in the fissures. Additionally, distinguishing a complex pleural collection, containing air and debris, from an adjacent parenchymal consolidation may not be possible.

Fluoroscopy also provides continuous real-time procedural guidance with the ability to monitor the needle, guidewire, and catheter during chest tube placement (►**Fig. 5**). Fluoroscopy can be used to access large collections or free-flowing pneumothoraces. However, fluoroscopy exposes patients to ionizing radiation and is limited for visualizing small or loculated collections.

CT provides a more comprehensive assessment of the extent of pleural disease with better soft-tissue contrast and a larger field of view. CT can be used to guide access into small, loculated, fissural, or paramediastinal collections or collections with intervening vital structures along the anticipated path of catheter placement. CT can aid in the drainage of air-filled pleural collections and collections adjacent to parenchymal consolidations (►**Fig. 6**). Unlike ultrasound, CT is not dependent on finding an adequate acoustic window. However, CT is more expensive, not always readily available, limits patient positioning and exposes patients to ionizing radiation. CT fluoroscopy allows precise image guidance with similar rapid, real-time advantage almost comparable to ultrasound and traditional fluoroscopy.[23]

Placement Techniques

Chest tube placement can be performed with the Seldinger technique, trocar technique, or blunt dissection. Ultimately, the choice of technique depends on the operator's

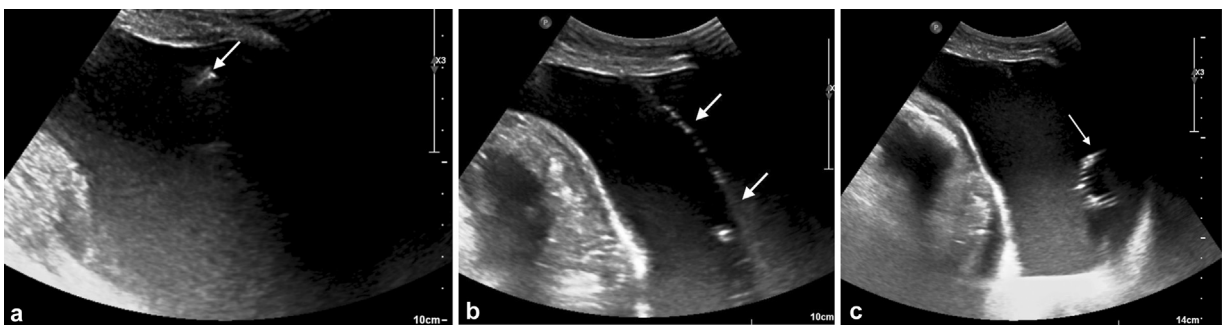

Fig. 4 A 66-year-old woman with fever and large complicated parapneumonic effusion requiring urgent chest tube placement for source control. (**a**) Gray scale ultrasound demonstrates free flowing pleural fluid. 5-Fr Yueh catheter (arrow) used to access the pleural space. (**b**) Ultrasound guidance was used to visualize guidewire (arrows) positioning in the pleural cavity and dilation was performed over the guidewire. (**c**) Ultrasound immediately after 12-Fr chest tube placement shows the catheter pigtail (arrow) in the appropriate position.

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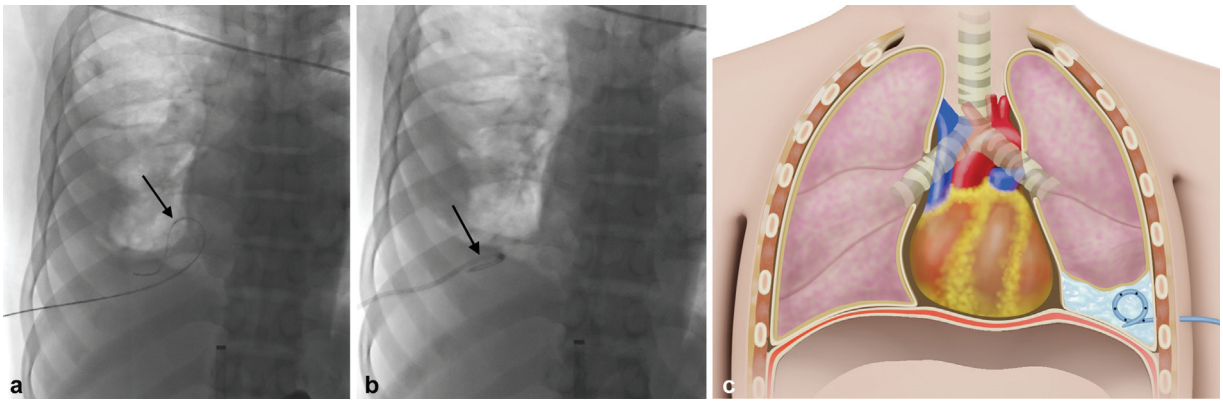

Fig. 5 A 74-year-old man with a history of hypertension and diabetes presenting with shortness of breath was found to have a large right pleural effusion on imaging. (**a**) Fluoroscopic guidance was used to place a single wall needle into the right pleural space with prompt return of straw-colored fluid. The guidewire (arrow) was advanced into the pleural space under fluoroscopy. (**b**) An 8.5-Fr pigtail catheter (arrow) was advanced over the guidewire with the pigtail formed in the lung base. The catheter was connected to a Pleur-evac set to −20 cm of water suction. (**c**) Illustration of chest tube placement directed inferiorly for pleural effusion.

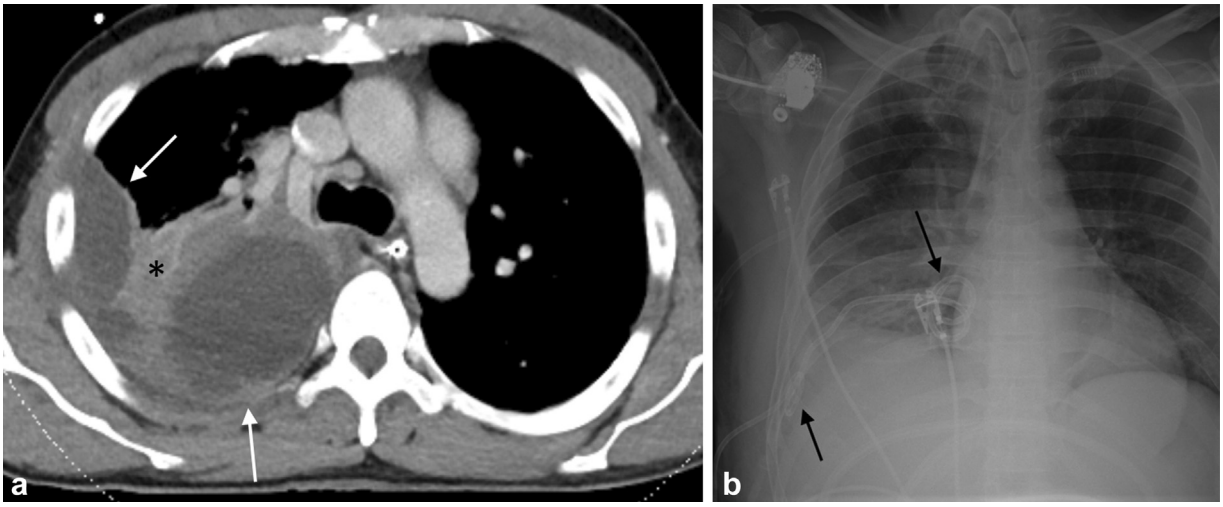

Fig. 6 A 43-year-old patient with acute high-speed motor vehicle trauma. (**a**) Axial CT of the chest with loculated right basilar fluid collections (white arrows) and adjacent parenchymal consolidation (asterisk) that was indistinguishable on sonography requiring CT-guided placement. (**b**) Frontal chest radiograph demonstrates two 10-Fr pigtail chest tubes (black arrows) placed within the loculated collections.

preference. The Seldinger technique is most commonly used for chest tube placement. Under image guidance, an access needle is advanced into the pleural space followed by insertion of a guidewire through the needle. The needle is removed and the tract is serially dilated over the guidewire followed by coaxial placement of the drainage catheter. The Seldinger technique is less traumatic and is associated with less pain and complications.[24]

The trocar technique involves direct puncture into the pleural space collection with a chest tube that contains an inner stiff coaxial needle. The trocar needle is removed once the system is in the field of drainage and the chest tube remains in place. The trocar technique allows for fewer steps and rapid chest tube placement. However, significantly higher rates of tube malpositioning and solid organ injury are associated with this technique.[25] In addition, tube repositioning is often more challenging.

Blunt dissection may be required for the placement of large bore catheters. A skin incision is made parallel to the rib space at the fourth or fifth intercostal space at the mid- to anterior axillary line for pleural fluid or the second intercostal space at the midclavicular line for pneumothorax. The soft tissue and intercostal muscles are bluntly dissected with a clamp going above the rib. The clamp is then used to puncture the parietal pleura and create a hole wide enough to allow finger exploration of the pleural cavity and break down adhesions. The chest tube is then guided into the pleural cavity.

Chest Drainage Systems

After a chest tube is positioned within the pleural cavity, it is connected to a closed chest drainage system. There are three types of chest drainage systems including three-compartment chest drainage system, one-way valve

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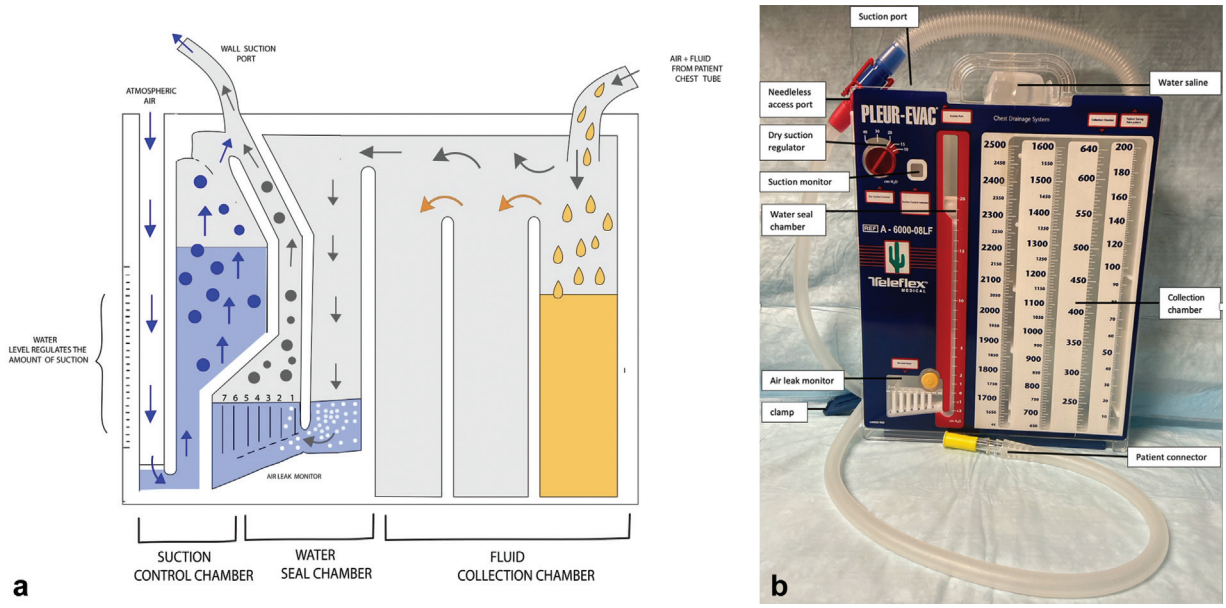

Fig. 7 (**a**) Illustration of a wet suction three-chamber chest drainage system. Pleural fluid drained by the chest tube will accumulate in the fluid collection chambers (yellow arrows). Air from the pleural space (black arrows) drained by the chest tube will flow into the water seal chamber and bubbling will be visualized in the air leak window. The suction port can be connected to wall suction. Atmospheric air (blue arrows) is drawn into the suction control chamber to regulate the amount of suction. (**b**) Image of a dry suction Pleur-evac three-chamber system. Note the dry suction regulator that controls the level of suction between −10 and −40 cm.

drainage system, and digital or electronic computerized drainage system.

Three-Compartment Chest Drainage System

The three-compartment chest drainage system, like the Pleur-evac (Teleflex, Morrisville, NC), is the most commonly used system. It contains a collection chamber, a water seal chamber, and a wet or dry suction control chamber (►**Fig. 7**). The collection chamber connects directly to the chest tube and collects drainage from the pleural cavity. It has a surface that can be marked with time and date of drainage.[26]

The water seal chamber acts as a one-way valve to allow air to exit the pleural cavity during exhalation but prevents reentry of air into the pleural cavity during inspiration. This preserves negative pleural pressure and permits lung reexpansion. The water seal chamber should always have a column of sterile water (2-cm water seal) to ensure proper functioning. Variations in pleural pressure during normal respiration will cause the sterile water to rise with inhalation and fall with expiration, which is known as tidaling. These variations will be reversed if the patient is on positive pressure ventilation. Tidaling is one indication that the chest tube is patent. If tidaling is not observed, an occlusion may exist somewhere between the pleural cavity and the drainage system, an air leak is present, the lung is fully expanded, or the oscillations are dampened by positive end expiratory pressure (PEEP). The water seal chamber may also have a calibrated manometer to measure the amount of negative pressure within the pleural cavity. Gentle bubbling is expected in the water seal chamber, as air is evacuated from the pleural cavity. Intermittent or continuous bubbling indicates the presence of an air leak which may be from inside the pleural cavity or along the external chest drain and tubing. All connections should be checked to ensure a proper seal. Chest tube position should be checked to ensure all the drain side-holes are completely within the pleural space. The chest tube can temporarily be clamped to identify if the air leak is coming from the patient or from the drainage system. It is important not to clamp for extended periods as that can cause an increase in pleural pressure resulting in a tension pneumothorax. The approximate air leak magnitude can be determined by the air leak meter existing in some systems. The meter is composed of numbered columns, labeled from 1 (low) to 7 (high). The lower the numbered column through which bubbling occurs, the lower the degree of air leak. This allows monitoring of the air leak to determine if further intervention is warranted.

Finally, the suction chamber regulates the amount of suction applied to the system and can be attached to continuous external suction or water seal with no active suction (gravity drainage). Suction can be adjusted up to −40 cm H_2O for a wet (water column) suction system versus a maximum of −25 cm H_2O for a dry (valve regulator) suction system. Water seal or suction of −20 cm H_2O is commonly chosen initially as normal pleural pressures range between 0 and −10 cm H_2O.[27] Suction is not always required and usage is individualized to the patient's condition. For pneumothorax, the argument for suction is that the negative pressure will facilitate expansion of the lung. The counter argument is that suction will keep a bronchopleural or alveolar–pleural fistula (APF) open and delay healing. A meta-analysis in post–lung surgery patients found that compared with water seal, suction prolonged length of stay, chest tube duration, and air leak duration, but suction drainage was beneficial in decreasing postoperative pneumothorax. There was no significant difference in occurrence of a PAL.[28] These results suggest there is no direct benefit to suction and this is in accordance with other meta-

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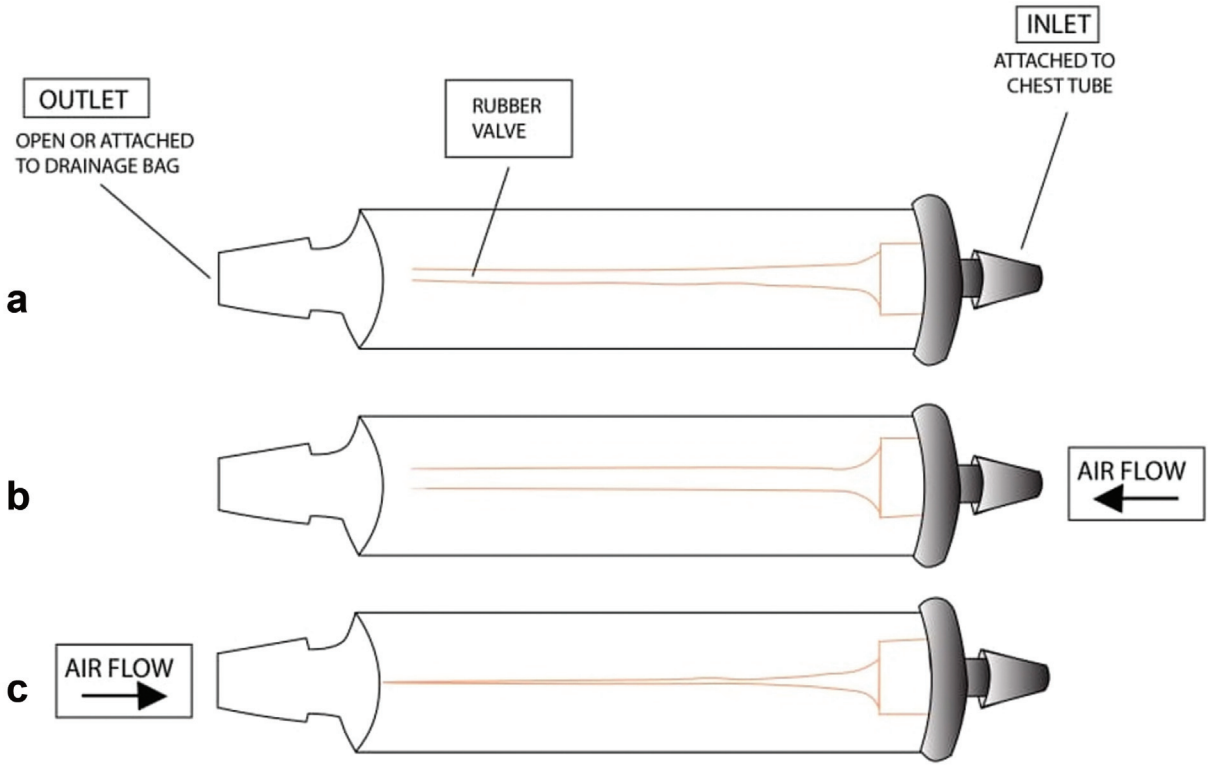

Fig. 8 Illustration of a Heimlich valve. (**a**) The valve consists of a rigid outer chamber and an internal collapsible rubber valve. The inlet nozzle connects directly to the chest tube and the outlet nozzle can be left open or connected to a collection bag. (**b**) Positive pressure is created within the chamber when air flows through the inlet nozzle from the chest tube. This distends the rubber valve allowing air to exit through the outlet nozzle. (**c**) During inhalation, negative pressure is created in the chamber causing the rubber valve to collapse and prohibits air reentry through the rubber valve.

analyses.[29,30] In clinical practice, a PAL without complete lung reexpansion is the most common reason to apply suction. For spontaneous air leaks, it is appropriate to use water seal or the least amount of suction to maintain a fully expanded lung. For pleural fluid, it is appropriate to increase the level of suction to achieve full lung expansion. Increased suction can help in expanding trapped lung.

Portable Chest Drainage Systems

Ambulatory chest drainage systems can be used to obviate or limit hospitalization which is cost-effective and increases patient satisfaction without compromising clinical outcome.[31] These devices consist of a combination of a compact and portable one-way valve, catheter tubing, and/or collection device. The one-way valve is designed to control the flow of air or fluid out of the pleural space during expiration and prevent reentry into the pleural space during inspiration. The Heimlich valve is the simplest method of portable pleural drainage that consists of a flutter one-way valve within a rigid plastic case that connects directly to a chest tube (►**Fig. 8**). A chest tube with a Heimlich valve can be left open to the environment, attached to a collection device, or attached to suction. A patient with a Heimlich valve drainage system can be discharged home with outpatient follow-up chest radiographs. Air passing through the valve creates a "flutter" sound and when the sound cannot be heard with expiration or Valsalva, the pneumothorax is either resolved or there is a clog in the system.[32] Lung reexpansion is verified with imaging prior to removing the chest tube.

Traditional flutter valves have a tendency to leak or clog leading to a risk of tension pneumothorax or pleural cavity infection. The latest innovations of compact portable one-way valve drainage systems, such as the Atrium Pneumostat (Atrium Medical Corp, Hudson, NH), address these issues by adding a 30cc collection chamber and air escape site for monitoring air leak. Portable thoracic vents consist of a small bore chest tube connected directly to a small air chamber device containing a one-way valve and self-sealing port (►**Fig. 9**). These devices are ideal for draining pneumothoraces with minimal to no pleural fluid component given the lack of a substantial collection bag. Additional portable chest drainage systems include wearable, compact, three-chamber chest drainage systems with larger capacity collection chambers up to 500 cc. The disadvantages for ambulatory drain systems include the need for home care services and possible noncompliance with outpatient follow-up.

Digital or Electronic Computerized Drainage Systems

Digital drainage systems were developed to standardize the subjective and variable air leak assessment. Digital chest drainage systems provide continuous pleural pressure assessments and objective quantifiable data about air leak and fluid drainage. These data facilitate decisions on when to remove a chest tube and on chest tube management.

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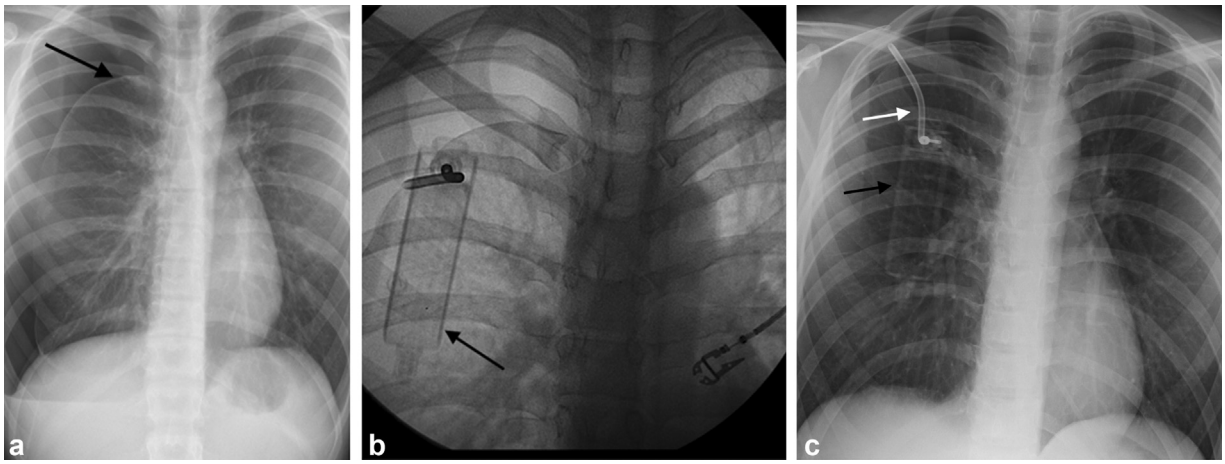

Fig. 9 A 22-year-old woman with no underlying lung disease presenting with shortness of breath and chest pain. (**a**) Frontal radiograph demonstrates a primary spontaneous pneumothorax (arrow). (**b**) ThoraVent catheter (UreSil Corporation, Skokie, IL) (arrow) was placed in the fourth intercostal space, midclavicular line under fluoroscopic guidance, and the patient was discharged with outpatient follow-up. (**c**) Frontal radiograph of the next day demonstrated stable position of the ThoraVent (black arrow) with intrapleural catheter (white arrow) and significant reduction in the size of the pneumothorax.

The system uses a pressure sensor, flow sensor, and infrared sensor to measure the pressure value, air leak volume, and drainage volume. Suction pressure is controlled by an installed vacuum pump and the sensor helps maintain a predetermined intrapleural pressure.[33] If the patient has an air leak, the device will intermittently apply suction to restabilize the pleural space according to the degree of the air leak. In general, a chest tube can be removed safely when the air flow is below a flow rate of 20 mL/min.[26]

Digital systems have gained popularity because they have been shown to be reliable in the detection of air leaks enabling earlier chest tube removal and shortening hospital stays when compared with conventional systems.[34] The digital drainage systems are compact with ambulatory suction and can be used in the outpatient setting. Furthermore, internet-based digital drainage system allows continuous real-time monitoring and management.[35]

Chest Tube Removal

Standardized guidelines for chest tube management are limited due to a paucity of evidenced-based literature. Following chest tube placement, patients should have daily monitoring to assess for the presence of an air leak and assess respiratory variation in the fluid column. Daily drainage output, tube positioning, and interval chest radiographs should also be evaluated. Stable clinical condition, absence of an air leak for 24 to 48 hours, and complete expansion of the lung are common criteria used to determine readiness for chest tube removal.

Chest tubes placed for pleural fluid are removed when the amount of pleural fluid produced does not pose a risk of reaccumulation requiring a repeat procedure. The standard drainage threshold for removal is less than 200 to 250 mL/day, but higher rates up to 450 mL/day can be considered in the absence of pleural disease.[36,37] A prospective study examined 150 post-lobectomy patients divided into three groups: chest tube removed at output of 150, 300, or 450 mL/d. Patients in the 150 mL/day group compared with those in the 300 and 450 mL/day group had no fluid reaccumulation but had increased chest tube days, increased postoperative hospital stay, and increased scores on a 5-day pain scale. The 300 and 450 mL/day groups had less chest tube days, less postoperative hospital stay, and reduced pain levels. However, the 300 mL/day group had 2 (4%) episodes of fluid reaccumulation compared with 11 (21.6%) episodes in the 450 mL/day group. One patient required thoracentesis after chest tube removal in the 300 mL/day group compared with eight patients in the 450 mL/day group, two of who required chest tube reinsertion. A drainage goal of 300 mL/day was concluded to be ideal for chest tube removal, with few reaccumulations but significant improvement in chest tube days, pain, and hospital length of stay.[38]

An uncomplicated pneumothorax that completely reexpands after chest tube placement can be safely managed as an outpatient with close interval follow-up and serial chest radiographs. Patients with a PAL, postoperative pneumothoraces, debilitated patients, and patients with severe underlying lung disease should be hospitalized. For both groups, once there is no longer an air leak and the lung remains expanded, the chest tube can be removed. A clamping trial can be performed before removal to assess for pneumothorax recurrence. Clamping a chest tube after resolution of an air leak can often detect a small air leak that was previously not readily apparent. A chest tube with an air leak should not be clamped, since this may lead to a tension pneumothorax. If the patient tolerates the clamping trial and there is no recurrent pneumothorax on chest radiograph, the chest tube can be safely removed.

Chest tubes should be removed during Valsalva or end expiration, which is associated with lower incidence of nonclinically significant pneumothorax.[39] An occlusive dressing with Vaseline or Xeroform gauze is preferred, or a stitch can be placed around the incision site and tightened when the tube is discontinued.

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Chest Tube Challenges/Complications

Complications during or following chest tube placement are uncommon and occur in less than 10% of cases.[40,41] The most common complications are insertion-related (malposition, pneumothorax, and hemothorax), infectious (chest tube site infection, empyema), and mechanical (tube dislodgement, tube kinking, tube occlusion). Other miscellaneous complications include pain and subcutaneous emphysema. Serious complications occur in 2 to 3% of patients and include significant postprocedure bleeding and hemothorax, visceral organ injury, and reexpansion pulmonary edema (REPE).[12,42]

Persistent Air Leak

The presence of an air leak suggests communication between the pleural space and pulmonary airspace via an APF or bronchopleural fistula (BPF). To check for air leak, the patient can be asked to cough or Valsalva. This creates bubbling in the water seal as the transient increase of pleural pressure forces pleural air to exit. If an air leak is observed for more than 5 to 7 days, it is defined as a PAL.[43] Secondary spontaneous and acquired pneumothoraces, post-pulmonary resection, pulmonary infection, and complications of mechanical ventilation are common causes of PAL. Intermittent chest tube drainage can also precipitate a spontaneous fistula if the pleura is compromised by underlying lung pathology. It is best to avoid overly aggressive drainage, which may promote fistula patency.

APF and BPF carry high morbidity and mortality. If the air leak persists despite chest tube drainage, further interventional and surgical repair may be required. Treatment options include a blood patch, intrabronchial valve, Heimlich valve, and video-assisted thoracoscopy. Thoracic surgery should be consulted early if there is a prolonged air leak.[26]

Persistent or Recurrent Pleural Collection

Incomplete evacuation or lung reexpansion can occur due to thick exudative fluid, malignant fluid, loculated collections, or trapped lungs (►**Fig. 10**). Multiloculated collections may require placement of multiple chest tubes. Fibrinolytics can be used to break down loculated fluid and thick debris such as alteplase 2 to 6 mg diluted in 25 to 100 mL sterile saline instilled for 1 to 2 hours, streptokinase 250,000 IU every 12 to 24 hours, or urokinase 100,000 IU daily.[44–47] The MIST2 trial showed that the combination of alteplase with DNase is beneficial for resolving loculated pleural effusions and empyemas and reduced the need for surgical referral and the length of hospital stay.[48] Tunneled indwelling catheter, pleurodesis, or surgical intervention can also be considered for managing persistent collections.

Arterial Injury

Hemothorax or hematoma is the most common complication following chest tube insertion and can lead to life-threatening hypovolemic shock or death.[49] For patients with suspected intercostal artery injury following chest tube placement, contrast-enhanced CT is useful in localizing the site of active bleeding. Transarterial embolization (TAE) is a minimally invasive option for rapid diagnosis and treatment

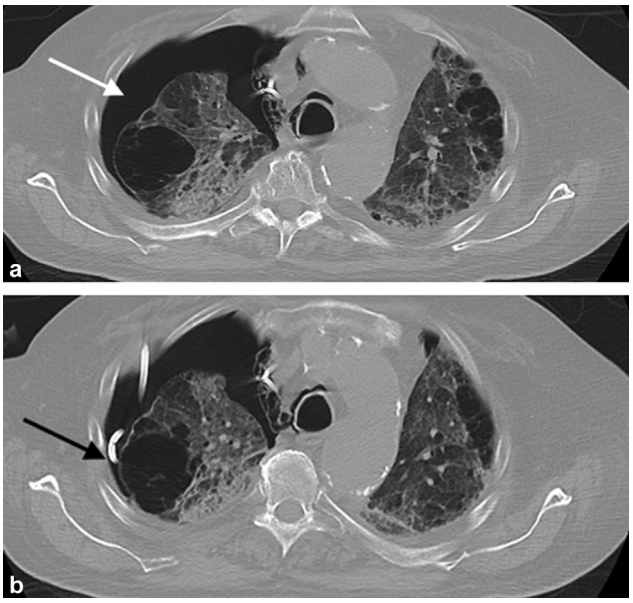

Fig. 10 A 65-year-old man with known interstitial lung disease and history of probable oxaliplatin pneumonitis. (**a**) Axial CT, lung window, demonstrates moderate right pneumothorax (arrow) with underlying moderate bilateral fibrosis and background emphysema. (**b**) Axial lung window demonstrates persistent pneumothorax following CT-guided placement of a 10-Fr pigtail chest tube (black arrow) consistent with trapped lung.

(►**Fig. 11**). Chest tubes can tamponade and mask an active bleed on angiogram. If the initial angiogram is negative, the chest tube can be removed over a wire and a repeat angiogram can be performed for further evaluation. If the patient is hemodynamically unstable and unable to undergo diagnostic angiogram and TAE, further surgical options may be needed including exploratory thoracotomy and VATS. To avoid bleeding complications in patients with coagulopathy, the procedure can be performed after transfusion of appropriate blood products.

Catheter Obstruction

Catheter obstruction is often a result of a kink or a clog in the tube from internal debris or blood clot. Clinical assessment with visual inspection or chest radiograph can rule out a kink in the tube. Clogged tubes can also be removed with simple saline flushes, wire passage to disrupt debris, or manual milking/stripping of the tubing. Caution is advised when stripping the tube, as this can result in a tension pneumothorax. Catheters can be flushed daily with 10 to 20 cc to help maintain patency.

Catheter Malposition

Malposition of percutaneous chest tubes is an uncommon complication but occurs in up to 30% of critically ill patients.[50] When catheter malpositioning is suspected, additional imaging, including low-dose chest CT, should be considered to verify the location of the tube (►**Fig. 12**). The chest tube should be replaced if the tube is malpositioned within an intrafissural, intraparenchymal, or mediastinal space. Further surgical consultation may be needed prior

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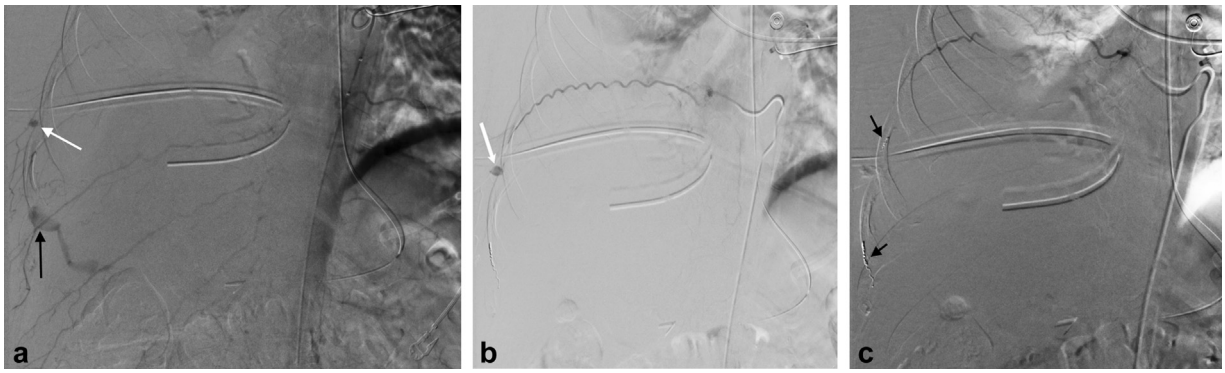

Fig. 11 A 51-year-old man status-post US-guided liver biopsy complicated by intercostal artery bleeding and hemothorax requiring 24-Fr chest tube insertion by blunt dissection at bedside. (**a**) Aortogram demonstrates active contrast extravasation from the 9th intercostal artery (black arrow) secondary to liver biopsy and from the 8th intercostal artery (white arrow) secondary to chest tube placement. (**b**) Selective 8th intercostal arteriogram demonstrates active bleeding (white arrow) adjacent to the site of tube insertion. (**c**) Post embolization angiogram of the 8th intercostal artery demonstrates hemostasis. Note coils (black arrows) at both sites of previously identified active bleeds.

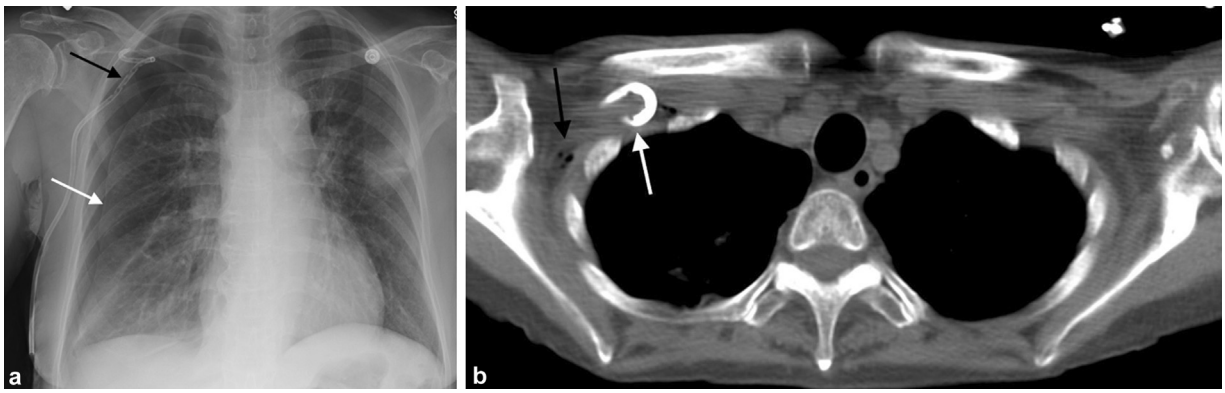

Fig. 12 A 67-year-old man presenting with blunt trauma to the chest. (**a**) Frontal radiograph shows persistent moderate apical pneumothorax (white arrow) with 10-Fr chest tube (black arrow) projecting over the lung apex. Chest tube was placed at the bedside without image guidance. (**b**) Axial CT of the chest obtained to evaluate persistent pneumothorax demonstrates the chest tube (white arrow) terminating in the right anterior extrathoracic soft tissues with surrounding subcutaneous emphysema (black arrow) consistent with malpositioning.

to replacement of a chest tube in the mediastinal space. Avoiding the use of trocar technique placement may reduce the incidence of tube malpositioning.

Reexpansion Pulmonary Edema

Reexpansion pulmonary edema is a potentially life-threatening complication following rapid drainage of pleural effusion or pneumothorax with an incidence of less than 1% and mortality rate of up to 20%.[51,52] Usually within 1 hour after drainage of pleural effusion or pneumothorax, patients may present with cough, progressive dyspnea, tachypnea, and low saturation levels (►**Fig. 13**). However, Jones et al found that REPE was uncommon even after 2 L of pleural fluid was drained as long as drainage was terminated when the patient

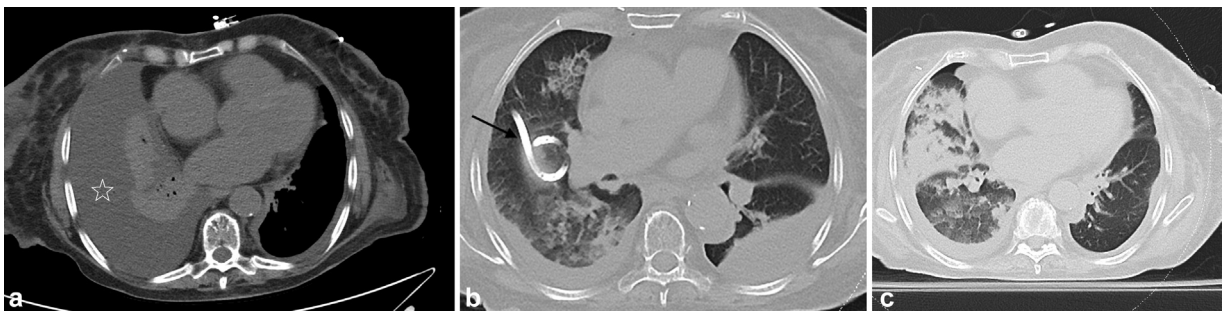

Fig. 13 An 86-year-old woman with a history of atrial fibrillation and well-differentiated squamous cell carcinoma of the anterior mandible. (**a**) Axial CT of the chest demonstrates a large right pleural effusion (star) with complete collapse of the right lung. (**b**) Axial CT of the chest demonstrates 14-Fr pigtail catheter (arrow) with significant decreased pleural effusion after drainage of 2.5 L of fluid. (**c**) Axial CT the next day demonstrates residual pleural effusion with diffuse patchy consolidations, ground-glass opacities, and septal thickening due to reexpansion pulmonary edema (compare with normal left lung).

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was symptomatic.[53] The treatment of REPE is supportive with oxygenation and continuous airway pressure support. In severe cases, intubation and mechanical ventilation with PEEP are needed.

Conclusion

Percutaneous chest tubes are a standard and reliable intervention to manage pleural effusions and pneumothoraces. Chest tube placement is a common procedure for interventional radiologists, as such, it is important to be familiar with all aspects including pleural space anatomy and physiology, classification of pleural diseases, chest tube management, and complications. The appropriate type/size of chest tube, chest drainage system, and drainage method are dependent on a multitude of factors that should be individualized to the particular patient condition. Imaging including ultrasound, CT, and fluoroscopy should be used to guide chest tube placement. All chest tubes are connected to a chest drainage system to allow air and fluid to be drained and to prevent air and fluid from reentering the pleural space. Chest tube removal is optimal when the patient is clinically stable, there is no air leak, pleural fluid drainage is diminished, and the lung is reexpanded. Complications related to chest tube placement are uncommon with the most serious including hemothorax, visceral organ injury, and REPE.

Conflict of Interest
None declared.

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